Chapter 41: Animal Nutrition

1. Overview of Animal Nutrition
2. Digestive Organs
3. Digestive Adaptations

The Need to Feed

Feeding satisfies 3 requirements:
1 – chemical energy to fuel cellular processes
2 – organic building blocks for macromolecules
3 – essential nutrients the animal cannot make for itself

Animals feed in 3 general ways:
- Carnivores – eat food derived from other animals
- Herbivores – eat food derived from plants
- Omnivores – eat food derived from both plants & animals
Essential Nutrients

Essential nutrients must come from the diet and are of 4 types:

- essential amino acids
- essential fatty acids
- vitamins
- minerals

Phospholipid and Prostaglandin Synthesis

Phospholipids

Fatty acid desaturase

*NADH

Linoleic acid

Essential Amino Acids

Animals require 20 amino acids to build proteins, roughly half of which are essential and must be obtained in the diet.

- most animal protein sources contain all essential amino acids (for humans) and thus are sources of complete protein
- most plant protein sources lack one or more essential amino acids and thus are incomplete protein sources

*R group is different for each amino acid

...more on Essential Amino Acids

Vegan diets must combine plant foods to get complete protein in a given meal.

- e.g., rice & beans, nut butter & bread

A few plant protein sources provide complete protein

- e.g., soy, quinoa, garbanzo beans (chick peas)

9 essential AAs for humans:

- isoleucine
- leucine
- lysine
- methionine
- phenylalanine
- threonine
- tryptophan
- valine
- histidine (infants only)
Essential Fatty Acids

Animals can synthesize most of the fatty acids they need however several such as linoleic acid are essential and must be obtained in the diet.

Most essential fatty acids are unsaturated (i.e., have 1 or more double bonds).

Vitamins

Vitamins are organic molecules required in the diet in minute amounts.

• there are 13 vitamins which are classified as “water soluble” or “fat soluble”

<table>
<thead>
<tr>
<th>Vitamin</th>
<th>Source</th>
<th>Major Functions in the Body</th>
<th>Symptoms of Deficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (retinol)</td>
<td>Dark green and orange vegetables, liver, fish, dairy products</td>
<td>Component of visual pigment involved in absorption and use of carotenes</td>
<td>Night blindness, skin disorders, impaired immunity</td>
</tr>
<tr>
<td>B (thiamine)</td>
<td>Noodles, rice, potatoes, meats, milk, eggs</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Nerve and brain damage, cardiovascular disease, mental and emotional disturbances</td>
</tr>
<tr>
<td>B2 (riboflavin)</td>
<td>Milk, eggs, liver, yeast, green leafy vegetables</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Severe dermatitis, eye disorder, sore throats</td>
</tr>
<tr>
<td>B3 (nicotinic acid)</td>
<td>Meats, liver, eggs, legumes, wheat germ</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Skin rash, diarrhea, dermatitis, nervousness, sore throats</td>
</tr>
<tr>
<td>B5 (pantothenic acid)</td>
<td>Meats, liver, eggs, legumes, whole grains</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Dermatitis, fatigue, muscle weakness, hair loss</td>
</tr>
<tr>
<td>B6 (pyridoxine)</td>
<td>Carbohydrates, legumes, nuts, poultry, milk, eggs</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Dermatitis, muscle weakness, numbness, fatigue</td>
</tr>
<tr>
<td>B7 (biotin)</td>
<td>Vegetables, fruits, lean meats, dairy products</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Dermatitis, muscle weakness, numbness, fatigue</td>
</tr>
<tr>
<td>B9 (folic acid)</td>
<td>Dark leaves, legumes, lentils, nuts, dried beans, enriched grains</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Fetal congenital abnormalities, anemia, skin rash, fatigue</td>
</tr>
<tr>
<td>B12 (cyanocobalamin)</td>
<td>Meat, eggs, liver, dairy products, fortified foods</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Fatigue, muscle weakness, numbness, psychiatric disturbances</td>
</tr>
<tr>
<td>C (ascorbic acid)</td>
<td>Citrus fruits, broccoli, tomatoes</td>
<td>Used in collagen synthesis; important antioxidant</td>
<td>Scurvy, degeneration of teeth and nails, hemorrhage</td>
</tr>
<tr>
<td>D (vitamin D)</td>
<td>Dark green and orange vegetables, fish, liver, dairy products, egg yolk</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Rickets, osteomalacia, and other bone disorders</td>
</tr>
<tr>
<td>E (tocopherol)</td>
<td>Seeds, nuts, vegetables, legumes</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Dermatitis, muscle weakness, numbness, fatigue</td>
</tr>
<tr>
<td>K (phylloquinone)</td>
<td>Green vegetables, legumes, seeds, nuts</td>
<td>Component of enzymes involved in energy production and metabolism</td>
<td>Dermatitis, muscle weakness, numbness, fatigue</td>
</tr>
</tbody>
</table>
Minerals

Vitamins are simple inorganic nutrients, most of which are required in small amounts.

Dietary Deficiencies

An individual suffers from malnutrition when the diet is deficient in essential nutrients (essential amino acids, fatty acids, vitamin and/or minerals) which can cause disease, deformities and death.

Undernourished individuals do not consume enough calories which leads to:

1. using up carbohydrate (glycogen), then fat stores
2. breaking down one’s own proteins – loss of muscle mass, protein deficiency in the brain
3. irreversible damage and/or death
The Main Stages of Food Processing

Digestion occurs at 2 levels:
- mechanical digestion (e.g., chewing) breaks up food to increase its surface area
- chemical digestion requires enzymes to catalyze the hydrolysis of polymers into monomers

Absorption is the uptake of nutrients into cells and elimination is the passage of undigested material from the body.

The Ingestion of Food

Suspension Feeders – filter food particles from a watery environment
Substrate Feeders – live in or on food source
Fluid Feeders – suck liquid nutrients from host
Bulk Feeders – eat large pieces of food

Digestive Compartments

A few animals digest material intracellularly in lysosomes (e.g., sponges), however most animals carry out extracellular digestion in a digestive compartment continuous with the outside of the animal’s body.
Most animals have a digestive tube with 2 openings – a mouth & anus – and thus have a complete digestive tract or alimentary canal.

- Ingestion, digestion, absorption and elimination occur sequentially in specialized compartments of the digestive tube.

2. Digestive Organs

The Mammalian Digestive System

- Alimentary Canal – oral cavity, pharynx, esophagus, stomach, small & large intestines
  - Passage of food material controlled by muscular sphincters
- Accessory Organs – salivary glands, liver, gall bladder & pancreas
The Oral Cavity, Pharynx & Esophagus

Mechanical & chemical digestion begins in the mouth as food is chewed.

- chewed food is mixed with saliva which contains amylase to chemically digest starch & mucus to lubricate the food bolus as it is swallowed through the pharynx and into the esophagus

(a) Trachea open (breathing)

(b) Esophagus open (swallowing)

Digestion in the Stomach

Mechanical & chemical digestion continue in the stomach:

- coordinated muscular contractions churn food to continue mechanical digestion
- pepsin, mucus & HCl (gastric juice) are added to begin the digestion of proteins
- the resulting mixture called chyme will eventually pass through the pyloric sphincter to the small intestine

Chemical Digestion in the Mouth & Stomach

<table>
<thead>
<tr>
<th>ORAL CAVITY, PHARYNX, ESOPHAGUS</th>
<th>STOMACH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CARBOHYDRATE DIGESTION</strong></td>
<td><strong>CARBOHYDRATE DIGESTION</strong></td>
</tr>
<tr>
<td>Polysaccharides (starch, glycogen)</td>
<td>Maltose</td>
</tr>
<tr>
<td>Disaccharides (sucrose, lactose)</td>
<td>Disaccharides (sucrose, lactose)</td>
</tr>
<tr>
<td>Salivary amylase</td>
<td>Maltase</td>
</tr>
<tr>
<td>Smaller polysaccharides</td>
<td>Smaller polypeptides</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>PROTEIN DIGESTION</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Pepsin</td>
</tr>
<tr>
<td>Small peptides</td>
</tr>
</tbody>
</table>
Digestion in the Small Intestine

Pancreatic juice containing bicarbonate (to neutralize stomach acid) and various digestive enzymes is released into the duodenum to complete the majority of chemical digestion.

**Chemical Digestion in the Small Intestine**

**SMALL INTESTINE (enzymes from pancreas)**

- **CARBOHYDRATE DIGESTION**
  - Disaccharides (sucrose, lactose, maltose)
  - Disaccharidases
  - Disaccharides
- **PROTEIN DIGESTION**
  - Small peptides
  - Amino acids
- **NUCLEIC ACID DIGESTION**
  - Nucleotides
- **FAT DIGESTION**
  - Glycerol, fatty acids, monoglycerides

**SMALL INTESTINE (enzymes from intestinal epithelium)**

- **CARBOHYDRATE DIGESTION**
  - Disaccharides (sucrose, lactose, maltose)
  - Disaccharidases
  - Monosaccharides

- **PROTEIN DIGESTION**
  - Small peptides
  - Amino acids

- **NUCLEIC ACID DIGESTION**
  - Nucleotidases
  - Nucleosidases and phosphatases
  - Nitrogenous bases, sugars, phosphates
The Role of Bile in Digestion

Bile is produced in the liver, stored in the gall bladder and released into the duodenum to aid in the digestion of fats (i.e., triglycerides to fatty acids).

- fats (lipids) are hydrophobic and insoluble in water
- bile emulsifies fats – disperses them into smaller droplets – to increase the collective droplet surface area to allow lipases to more efficiently encounter and digest fats

Absorption in the Small Intestine

Digestion is more or less completed in the duodenum and most absorption occurs along in the jejunum and ileum.

- folds, villi & microvilli dramatically increase the surface area for absorption in the small intestine

The Absorption of Fats

- epithelial cells lining the small intestine absorb fatty acids and monoglycerides through the apical surface which are reformed into triglycerides within the cell
- triglycerides are combined with other lipids and special proteins to form soluble aggregates called chylomicrons
- chylomicrons are transported across the basal surface into lymphatic lacteals in the center of each villus and carried to the liver via the lymphatic system
**Blood Transport from Small Intestine to Liver**

- All non-lipid nutrients are transported across the intestinal epithelium to capillaries in each villus and to the liver via the hepatic portal vein.
- Blood-borne nutrients and toxins are processed in liver sinuses before the blood enters the vena cava to the rest of the body.

**Processing in the Large Intestine**

The large intestine consists of the cecum, colon & rectum:

- The cecum aids in the fermentation of plant material and is connected to the appendix which has a role in immunity.
- The colon is full of beneficial bacteria that aid in digestion and nutrient production.
- The colon reabsorbs water to minimize water loss and to compact feces which is stored in the rectum before elimination.

**Summary of Digestion & Absorption**
3. Digestive Adaptations

Dental Adaptations

- A big part of the success of mammals is the evolution of specialized teeth tailored to the diet of the animal.

Gut Structure Correlates with Diet

The digestive tracts of animals are variations on an ancestral plan that evolved to be more complex and specialized for processing a variety of food sources.
**Stomach & Intestinal Adaptations**

- Carnivores tend to have large, expandable stomachs and relatively small large intestines.
- Herbivores tend to have longer large intestines and a large cecum to handle more difficult to digest plant material.

**Mutualistic Adaptations of Herbivores**

Many herbivores have complex digestive systems that depend on mutualistic microbes to help digest cellulose and other plant materials in compartments that serve as fermentation chambers.

- Ruminants have the most advanced herbivorous digestive systems.

**The Role of Feedback Mechanisms**

- The hormones gastrin, secretin, and cholecystokinin (CCK) have important roles in regulating the release of digestive substances.
• **insulin & glucagon** produced in the pancreas work together in reciprocal ways to maintain blood glucose homeostasis.

**Regulation of Appetite**

- ghrelin produced in multiple digestive organs stimulates appetite when the stomach is empty
- leptin produced in adipocytes suppresses appetite and regulates levels of stored fat
- insulin from the pancreas & peptide YY (PYY) produced in the small & large intestines after meals also suppress appetite